Lab #2

Introduction

The goal of the home part of this lab is to measure the impedances of the capacitor and the inductor and to extract their capacitance and inductance correspondingly. As part of this project we will convert the output of the Sound Blaster into a current source by adjusting its output impedance. By analyzing the ratio of the output impedance of the current source, input impedance of the oscilloscope, and the impedance of the component under the test, we will find the regime where both the current source and the oscilloscope work as ideal instruments and measure the magnitude and the phase of these components.

Home part of the lab

Converting the Sound Blaster output to a current source

An ideal current source has INFINITE output impedance. It drives all current through the load and there is no current flowing through the current source. The real current source has a large, but finite, output impedance. It could be represented by a Norton equivalent circuit (see Figure 1) which is composed of an ideal current source I_N and a parallel resistor R_N (see 1.7 of the textbook for reference). This resistor provides an additional path for current, resulting in smaller current through the load. This effect is significant when the load impedance is comparable or larger than the output impedance of the current source.

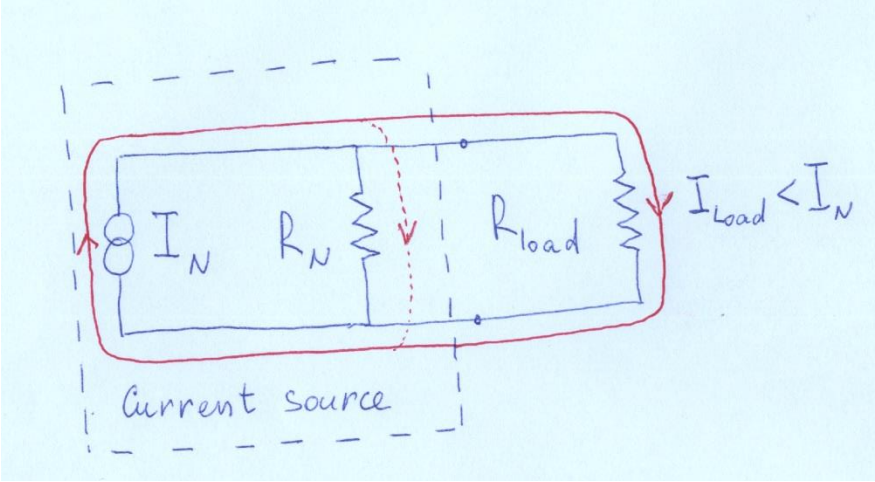


Fig. 1. Current distribution in a Norton equivalent circuit of a current source with finite output impedance R_N and connected load R_{load}.

Recalling that Thevenin and Norton circuits describe the same two terminal networks if their resistors are identical, we can convert the Sound Blaster output to a current source just by adjusting its R_{th} output impedance to the desired value (see Figure 2). The Norton current I_N of such a current source depends on V_{Th} and R_{Th} as:

$$I_N = \frac{V_{Th}}{R_{Th}}$$

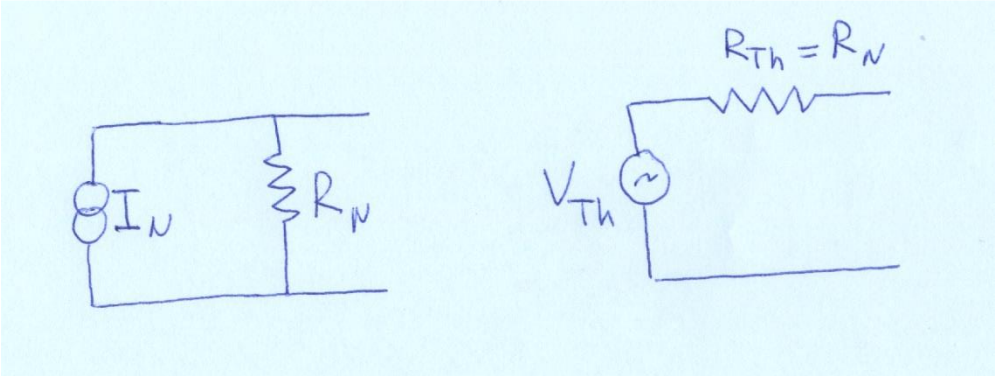


Fig. 2. Norton equivalent circuit of a current source (a) and its Thevenin equivalent (b).

Take a 100 KOhm resistor from your resistors kit and convert Channel 1of the Sound Blaster output to a current source with output impedance of 100 KOhm.

Measuring capacitance of an unknown capacitor

Let's use the current source we have just built to measure the capacitance of an unknown capacitor.

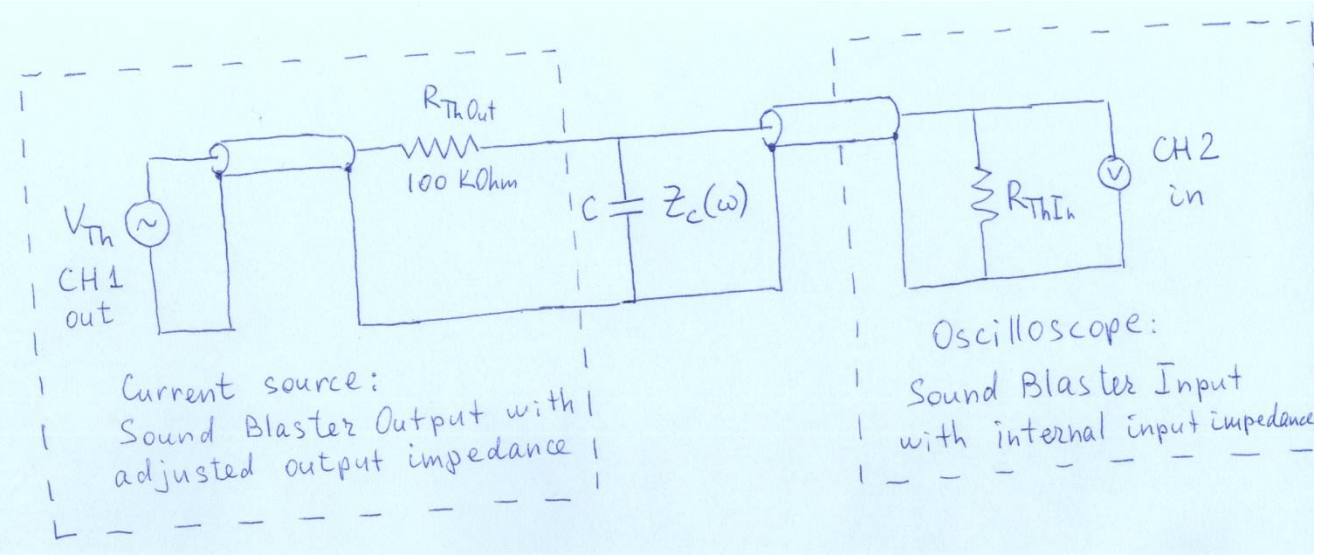


Fig. 3. Circuit schematic for measuring the magnitude of the impedance of the capacitor. Current source is shown as its Thevenin equivalent. Internal input impedance of the oscilloscope $R_{Th\,In}$ is shown.

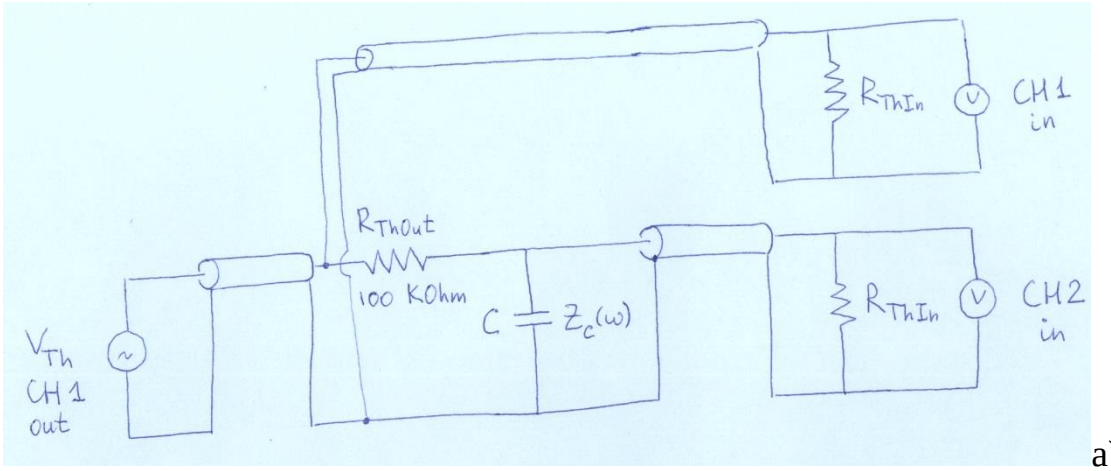
Use the modified Channel 1 of the Sound Blaster to drive current through the capacitor, and Channel 2 of the Sound Blaster input to measure the voltage V across the capacitor (see Figure 3). Set the amplitude of V_{Th} to 1 V and the frequency to 100 Hz. Before taking any measurements we have to analyze the interplay between the output impedance of the current source $R_{Th\,Out}$, the input impedance of the oscilloscope $R_{Th\,In}$ (the Sound Blaster input impedance that you

have measured in the previous lab), the impedance of the capacitor $Z_C(\omega)$ and how their ratio affects the measurement of the capacitor impedance.

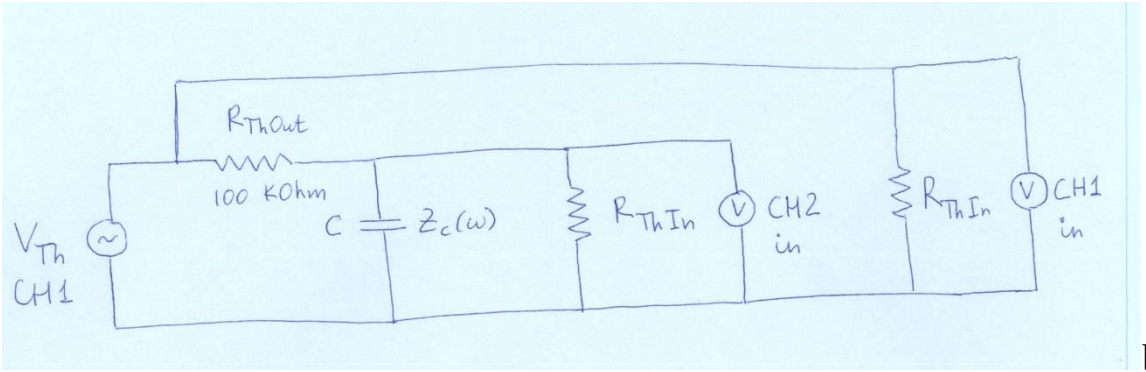
First, the impedance of $Z_C(\omega)$ and $R_{Th\ In}$ in parallel (load for the current source) should be much smaller than the output impedance of the current source $R_{Th\ Out}$. In this case, the current at the output of the current source is equal to I_N and it could be considered as ideal. Second, the capacitor impedance $Z_C(\omega)$ should be much smaller than the input impedance of the Sound Blaster $R_{Th\ In}$. In this case, almost all the current I_N flows through the capacitor, the measured voltage V depends only on $Z_C(\omega)$, and the Sound Blaster could be considered as an ideal oscilloscope. How do we make sure that $Z_C(\omega)$ is small enough to satisfy both conditions if we do not know its value yet? If you remove the capacitor for a moment, the measured voltage will be defined by the ratio of $R_{Th\ Out}$ and $R_{Th\ In}$. Now plug the capacitor back in, and adjust the frequency in such a way that the measured voltage gets much smaller than it was without the capacitor (keep it high enough to be able measure it; a few mV amplitude should be enough). Making the voltage with the capacitor in place much smaller than without the capacitor ensures that $Z_C(\omega)$ is much smaller than the input impedance of the Sound Blaster $R_{Th\ In}$. If so, than $Z_C(\omega)||R_{Th\ In}$ is almost equal to $Z_C(\omega)$ and is much smaller than the output impedance of the current source $R_{Th\ Out}$. Measure the amplitude of the voltage across the capacitor, calculate the magnitude of its complex impedance, and extract the capacitance (see 2.7 of the text book for reference).

The voltage across the capacitor and the current flowing through it have a different phase because of the complex nature of a capacitor's impedance. To measure this phase shift we have to compare both current and voltage signals. We are already measuring the voltage V across the capacitor using Channel 2 of the

Sound Blaster. Unfortunately we cannot measure the current through the capacitor in our current setup. But we do not have to. Instead we can measure V_{Th}, because its phase is equal to the phase of current I_N through the capacitor. Connect the Channel 1 of the Sound Blaster input directly to the Channel 1 of the Sound Blaster output to measure V_{Th}.



a)



b)

Fig. 4. (a) Circuit schematic for measuring the magnitude of the impedance and the phase shift between V_{Th} and voltage across the capacitor (b) and its simplified version.

Two versions of the complete measurement circuit are shown in Figure 4 a and b. They are identical, but Figure 4 a shows all the wires as they are (signal and ground wires go together forming cables, for example), and Figure 4 b is a

simplified version where the wires show just the electrical connections without showing their real physical positions. It makes the circuit diagram less crowded.

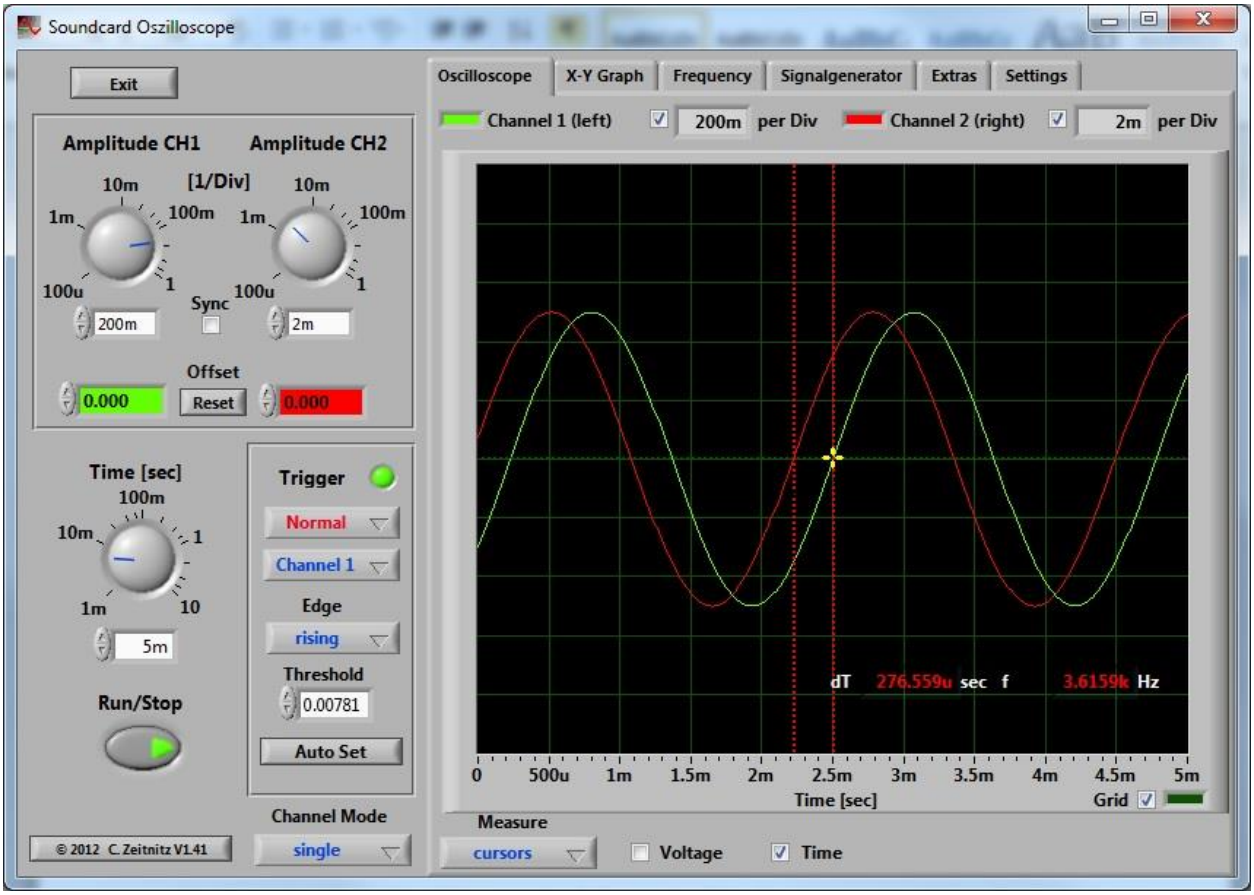


Fig. 5. Screen shot of the Soundcard Oszilloscope program showing the settings for measuring phase difference between two signals.

Uncheck the **Sync** check box on the left panel of the **Soundcard Oszilloscope** program to adjust independently the voltage scale settings of Channel 1 and Channel 2 (see Figure 5). Choose **Cursors** option from **Measure** drop list and check **Time** check box to measure the phase between V_{Th} and V_C. Move one vertical cursor to the point where V_{Th} phase is equal to zero, and another cursor to the point where voltage across the capacitor has phase equal to zero. **dT** in the right bottom corner of the oscilloscope screen shows the time difference between

these two points. Convert this time difference in phase difference. Is measured phase shift consistent with expected? **Report measured capacitance and phase shift between current flowing through the capacitor and voltage across it. Show your math.**

Measuring inductance of an unknown inductor

Follow the procedure for measuring capacitance and measure the inductance of the inductor. **Report measured inductance and phase shift between current flowing through the inductor and voltage across it. Show your math.**

Note: Take a DMM and measure the resistance of the inductor. Estimate what would be the voltage cross the inductor if this parasitic resistance is the only source of the inductor impedance. Keep the frequency of the signal high enough to have the voltage across the inductor much higher than estimated. In this case the contribution of this parasitic resistance into the impedance of the inductor will be negligible and the phase shift between current and voltage signals will correspond to that of ideal inductor.

In-class part of the lab

The goal of this in-class part of the lab is to study the transient responses of RC, LC and LCR circuits (see 2.3.1 - 2.3.3 in the text book). You will also learn how to use the synchronized output of the function generator to trigger the oscilloscope. We will also start to use Matlab for data processing.

First, you have to build the circuit, shown on Figure. 1. This circuit contains the inductor *L* and the capacitor *C* (components from the home part of this lab), and a 10 KOhm potentiometer *R*. A potentiometer is a variable resistor with three legs. Resistance between two of the legs is constant and equal to 10 KOhm. The third leg is a sliding contact which slides between the first two. By changing its position, the resistance between the sliding contacts and others could be adjusted to any value between 0 and 10 KOhm. Use the DMM to identify the legs.

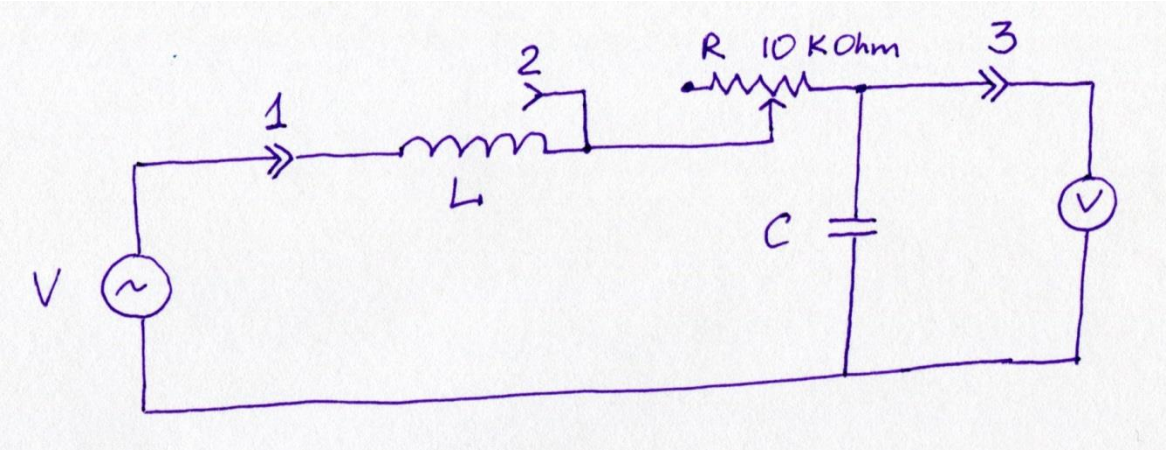


Fig. 6. Circuit schematic for studying the transient response of RC, LC and LCR circuits. All input, output and parasitic impedances are not shown. Symbols numbered as 1, 2 and 3 correspond to the 3 BNC connectors on the front panel of the printed circuit board.

We will use all three BNC connectors available on the print board panel. These connectors are numbered from 1 to 3 on the circuit diagram (mostly for convenience). When the function generator is connected to the BNC connector #1, we have either an LC circuit, if the potentiometer is set to zero resistance, or else an LCR circuit at any other value of *R*. When the function generator is connected to the BNC connector #2, we have an RC circuit. Channel 1 of the oscilloscope is connected to the BNC connector #3 and measures the voltage across the capacitor. The circuit diagram shows only physical components. All output (signal generator, 50 Ohm), input (oscilloscope, 1 MOhm) and parasitic (inductor, you have measured it in the home part of the lab) impedances are not shown. **If some of these impedances affect your next measurements, draw the corresponding circuit diagram which include those impedances which are important. If you think that some of these impedances could be neglected, explain why.**

One significant difference of our circuit diagram from the text book circuit diagrams 2.4-2.6 is the presence of the signal generator. We will use it to apply a square wave signal to the input of the circuit. Every time the input voltage swings between the high and low values, the voltage across the capacitor gradually decays from one voltage to another. This transient response depends on the parameters of the circuit, and is the subject of this part of the lab.

Transient response of the RC circuit

Build the circuit shown in Fig. 1. Set the resistance of the potentiometer to 10 KOhm. Split the signal generator signal using a T adapter, and apply it to the BNC connector #2 and to Channel 2 of the oscilloscope. Set the wave form of the signal to a square wave. The amplitude of the signal could be anything; it is just a matter of convenience. **Calculate the time constant $\tau=RC$ of the RC circuit and**

report it. Set the period *T* of the signal so that the voltage across the capacitor has enough time to completely decay ($T >> \tau$).

First trigger the oscilloscope with the circuit output signal. Set the trigger slope to **Falling** and the trigger level to any value between the minimum and maximum values of the input signal (page 99 of the User Manual). Because the output voltage exponentially decays with time, it is hard to set the trigger level so the trigger time will be fixed in time when the input voltage jumps from one value to another (actual reference time for the transient response). Play with the trigger level and you will see what I mean. To do so, we can trigger the oscilloscope with the input signal. Change the trigger source of the oscilloscope in Channel 2. Now the reference time is fixed to the moment of the input voltage step.

Save the waveform of the transient response. Login into your lab computer using your NetID and password. Open Matlab and the script prepared for this lab. The script is extensively commented and designed to teach you how to import measured data, plot them, compare with the theoretically predicted exponential decay, and extract the real time constant of the measured exponential decay. **Plot your data, and save the image for your report. Report the measured time constant.**

Transient response of the LC circuit

Switch the signal generator cable to BNC connector #1. Set the value *R* of the potentiometer to zero. According to the circuit diagram, we have now an LC circuit and the transient response should be a sine wave (see 2.3.2 of the text book). **Why is it not a sine wave but instead it looks like an underdamped LCR circuit? What is the source of the dissipation?**

Transient response of the LCR circuit

Play with the value of the potentiometer resistor *R*. Watch how the transient response changed from underdamped to overdamped. Calculate the value of *R* for the critically damped LCR circuit. **Report it. Show your work.**

Take a close look on the input signal. When the LCR circuit is extremely underdamped the input signal is distorted. **Here is a question for an additional 5 points: explain why the input signal is distorted for an underdamped LCR circuit.** Because the input signal is distorted, it is not an ideal source for triggering the oscilloscope. The function generator has an additional output located on its rear panel. It is a **Sync Out** connector. Its output is a 0-5 V square wave synchronized with the Channel 1 output signal. Set the **Sync Output** signal (page 2-50 of the User Manual), connect the **Sync Out** connector to the **Ext Trigger** connector of the oscilloscope, and set the oscilloscope trigger source to **External** and the trigger level to 2.5 V. Now you can trigger the oscilloscope with an external signal that is not connected to the circuit under test (and therefore is not affected by the circuit), is synchronized with the input signal, and has a conveniently large amplitude.

Save waveforms of underdamped and overdamped waveforms of the LCR circuit, plot them together and include in your report.